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Roadscanner: Feasibility study and development of a GNSS-probe for creating digital maps of high accuracy and integrity.

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Abstract

This paper describes the main outcome of the Roadscanner project, in developing a Vehicle Probe prototype equipped with a Global Navigation Satellite System (GNSS) receiver, an Inertial Navigation System (INS) and a Laser Scanner (LS) unit to create digital maps of high accuracy and integrity.
GNSS have become an important factor in transport with limitless possibilities. The GNSS concept is based on a constellation of satellites that provides autonomous geo-spatial positioning with global coverage. This enables GNSS receivers to calculate a Position Velocity Time (PVT) solution using the signals transmitted from satellites along the line-of-sight to the receiver. Following the obvious application of navigation and guidance for various types of vehicles, the advances in accuracy and integrity of PVT have enabled other uses, such as Advanced Driver Assistance Systems (ADAS) and digital automotive simulations. However, GNSS also has intrinsic limitations (subject for example to radio-frequency interference, signal availability and vehicle dynamics), which can be a serious hindrance for demanding applications, where accuracy and integrity are critical.
In order to remedy GNSS drawbacks, the satellite receiver data can be integrated with additional sensors, such as an INS. The sensor fusion provides a solution of enhanced accuracy, robustness and integrity and also yields attitude information. Furthermore, adding a laser scanner (LS) provides road surface measurements, which are important for simulation, or road surface quality inspection.

Keywords: GNSS; INS; Laser Scanner; navigation; digital maps; road surface

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1. Introduction

1.1. Background

Following Greece's accession to the European Space Agency (ESA), a number of projects were assigned to Greek companies by the ESA under the 1st and 2nd Call for Ideas. NIKI Ltd, having a strong automotive research and industrial partner background, was assigned the feasibility study for a vehicle probe that would combine the required sensors (GNSS, INS and LS) for the creation of accurate digital maps and the subsequent development of the probe. The project comprises of both Hardware (HW) and Software (SW) development, as well as, market research for the applicability to the automotive, construction and navigation industry.

Nomenclature

3D	3 Dimensional
ADAS	Advanced Driver Assistance Systems
COTS	Commercial off the shelf
EGNOS	European Geostationary Navigation Overlay Service
EKF	Extended Kalman Filter
ESA	European Space Agency
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HW	Hardware
INS	Inertial Navigation System
LS	Laser Scanner
OEM	Original Equipment Manufacturer
PC	Personal Computer
PPP	Precise Point Positioning
PVT	Position Velocity Time
RINEX	Receiver Independent Exchange Format
RTK	Real Time Kinematic
SBAS	Satellite Based Augmentation System
SW	Software

1.2. Project Goals

As the existing GNSS (Gleason & Gebre-Egziabher, 2009), such as GPS and GLONASS, have been available for well over three decades, their limited accuracy, reliability and integrity prevent any advanced use in safety critical and precision demanding applications. As a consequence, the same holds true for publicly available GPS or GLONASS generated digital maps, since they were not compiled with the above mentioned precision and safety criteria in mind.

Today's available digital maps and GNSS positioning options are adequate for turn-by-turn navigation applications. The ongoing research in advanced road passenger safety has already defined new precision requirements (Toledo-Moreo & Zamora-Izquierdo, 2010) to enable incorporation of digital maps in safety critical applications and ADAS. Some examples, for which the automotive industry has already defined the preliminary requirements, are systems for vehicle control, driver warning and exact path prediction.

In addition, the novel use of digital three dimensional (3D) road surfaces in the vehicle engineering process has increased the market demand for precise datasets in advanced automotive simulations concerned with road-tire-vehicle interaction (Li & Lei, 2010). The simulation of the vehicle mechanical system can be enhanced with the use of accurate input for the road geometry, in terms of its geometric characteristics, such as slope, elevation and curvature enhanced with meta-data for their surface properties.

The required accuracy and integrity of digital maps for the forthcoming applications can be achieved through the utilization of the latest sensor technology in combination with the more reliable, precise and publicly available European navigation systems such as EGNOS and Galileo. The Roadscanner methodology will refine existing digital maps with the use of appropriate algorithms in terms of precision and integrity. The combination of those technologies will lead to digital map products/datasets certified and verified for use in safety critical applications.

2. Project Description

2.1. Outline

The project consists of a design and implementation phase for the system HW and respective SW, a market research phase and a deployment and demonstration phase. It was conceived as an integration of commercial off the shelf (COTS) equipment, for cost and versatility reasons. The basic platform is a common vehicle with minor modifications, necessary for incorporating the necessary instruments. The rest of the HW consists of standard notebook Personal Computers (PC), specialized measuring equipment and the respective interconnections. The required HW is commercially available from several Original Equipment Manufacturers (OEMs). Fig. 1 displays a conceptual design of the system.

The system SW is designed to operate the probe, collect data and perform data integration and storage. A modular approach is used for the implementation of the platform's SW. A major part of the SW design and implementation is the development of the data fusion algorithms. In line with the majority of navigation applications, an Extended Kalman Filter (EKF) (Farrell & Mathew, 1998) is selected to combine GNSS and INS data. Fig. 2 displays a conceptual overview of the SW, as well as the information flow between SW modules.

In order to access the market potential of the project, a market research study was carried out with on line questionnaires addressed to key market players. In particular, automotive OEMs and suppliers, tire manufacturers, navigation services providers and road construction companies. At the moment, the project is still under development, pending the final implementation of the data fusion algorithms, the completion of the SW development and the final operational tests and demonstration. The current platform assembly and results are presented in the following sections.

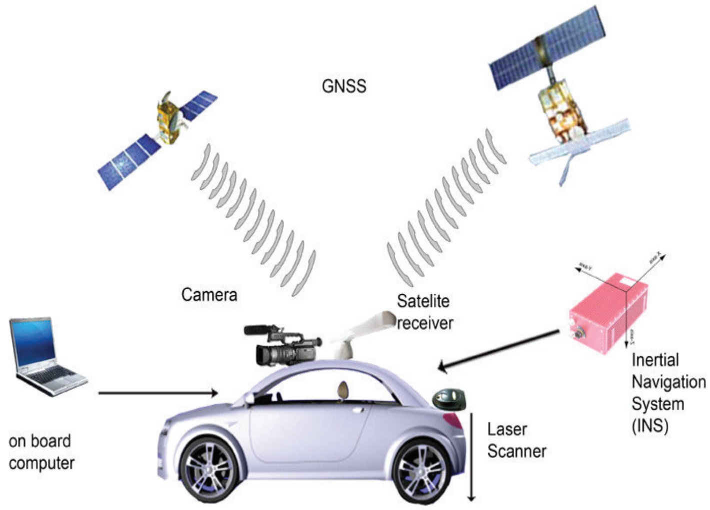

Fig. 1. Vehicle Probe Conceptual Design.

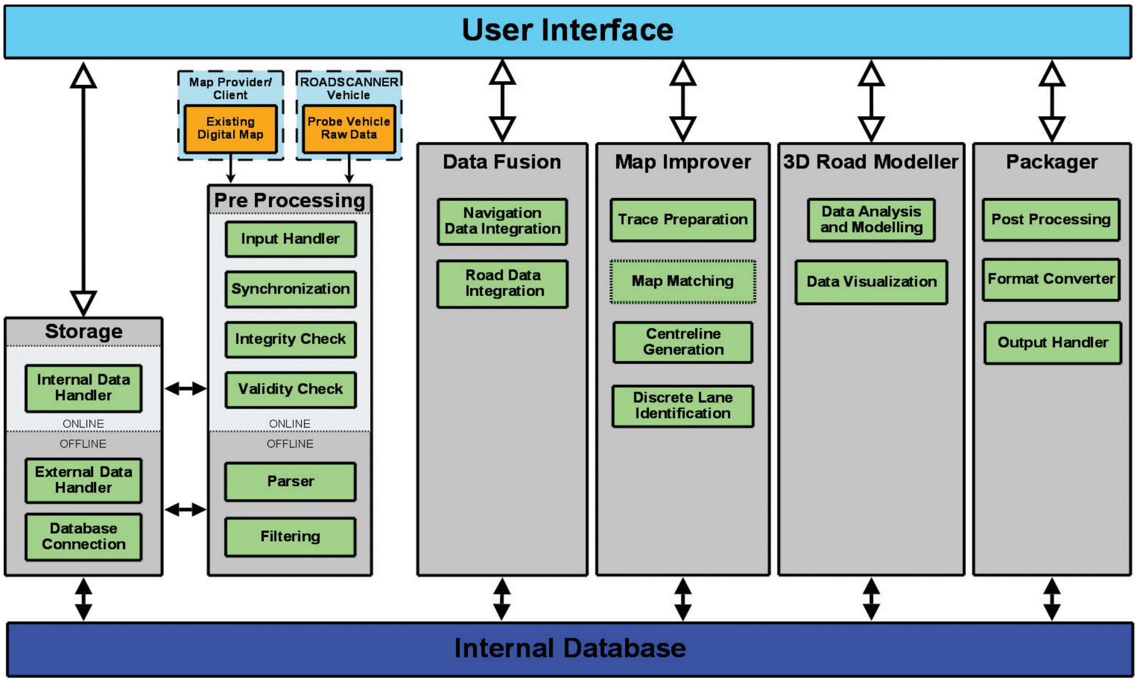

Fig. 2. Software overview.

3. Platform Assembly

3.1. HW Description

The platform assembly is shown in Fig. 3. The GNSS configuration employed utilizes two Topcon GR-3 receivers. The first receiver is mounted on the vehicle and the second is placed on a known position. Thus, they can perform in differential mode, preferably in post processed Real Time Kinematic (RTK) mode (Takasu, Kubo & Yasuda, 2007) in order to achieve maximum accuracy. The receivers are capable of receiving GLONASS and SBAS messages, thus adding to the availability, accuracy and integrity of the collected data.

The inertial data, accelerations and angular rates, are collected with the Crossbow AHRS 440CA-200 INS. The specific system is a typical Micro Electro Mechanical System (MEMS) INS, which utilizes GNSS derived information for timing, heading and attitude corrections.

The road surface data are collected with the SICK LMS 291 S0-05 laser scanner. This device operation principle relies on measuring the time of flight of emitted laser pulses, thus calculating the distance to the targeted point.

INS and LS data are collected with serial port interfaces to the PC and synchronized with GPS time, provided by the GNSS receiver serial port. GNSS data are collected in the industry standard Receiver Independent Exchange Format (RINEX) format onboard the receiver's internal memory.

Fig. 3. Roadscanner platform assembly

3.2 Operation principle

The prime objective of the project is to provide an accurate representation of a traveled route, in terms of global position information and road surface geometry. The use of GNSS information can provide accuracy, when a technique like RTK or PPP (Dow, Neilan & Rizos, 2009) is used; however it is prone to outages and cannot provide the orientation of the vehicle probe. The INS system, when combined with a GNSS, can assist in positioning during signal outages, as well as provide orientation information. Thus, the GNSS and INS data fusion can fully describe the motion of the vehicle, with respect to an inertial reference frame.

When both position and orientation are known, the point distance information collected by the LS, which is also mounted rigidly on the vehicle, can be resolved to an inertial frame and used to describe the road surface, usually by creating a 3D triangulated mesh.

3.3 Algorithm description

The algorithm employed for the GNSS and INS data fusion is an EKF implementation. The INS measurements are used to provide the system model through numerical integration of the equations of motion, while the GNSS PVT solutions or pseudo range measurements form the respective measurement model. The 15 state vector contains the vehicle position, velocity and attitude, as well as the biases of the accelerations and angular rates provided by the INS. The INS model employed relies on over-bounding measurement errors (Xing & Gebre-Egziabher, 2008).

Both loosely and tightly coupled versions have been implemented, depending on the selection of the measurement model. In the loosely coupled implementation the system innovation is the difference between the model predicted position and velocity of the vehicle and the position and velocity as reported by the GNSS receiver. In the tightly coupled implementation, the system innovation is the difference between the receiver measured pseudo-ranges and the pseudo-ranges calculated using the predicted positions of the vehicle and satellites.

4. System Tests and Current Results

4.1 System Configuration

Following platform assembly, a series of operational tests were carried out. The tests consisted of GNSS and INS data collection in several routes and post processing of the data collected. The GNSS configuration consisted of a static base receiver and a rover receiver mounted on the vehicle. The INS was also mounted on the vehicle and connected to the rover receiver, accepting GPS NMEA messages. Both the GNSS receivers stored data in their internal memories in RINEX format. The INS data were collected in real time via a serial port connection to the PC.

4.2 GNSS Data Processing

Out of several techniques that have been developed for enhancing the positioning accuracy of GNSS systems, the current implementation of the project has adopted RTK and PPP. RTK is implemented via use of the RTKLIB library and uses data from both receivers for an accurate PVT solution. PPP (Heroux & Kouba, 2001) is used to acquire an accurate positioning solution for the base receiver, as well as to post-process the rover receiver data and provide an accurate PVT solution for the rover receiver.

While RTK uses differential techniques, PPP relies on post processing and the existence of accurate GNSS and atmospheric data, such as ephemerides or ionosphere and troposphere conditions. However, both techniques can provide decimeter accuracy and compliment each other for the purposes of this project. In particular, RTK post processing can provide an accurate solution right after data collection, while PPP provides maximum accuracy after a few days when precise ephemerides become available. On the other hand PPP provides the position of the base receiver, without the need for a priori known landmarks. Since both methods are considered accurate, major differences between them can reveal shortcomings in the system's performance.

4.3 INS Data Processing

INS data consist of accelerations and angular velocities. The acquired data are in known rates, however their timing information is provided with reference to internal clocks, either of the connected PC or of the device itself. This timing information is erroneous both in terms of original time reference, as well as prone to accumulating time errors. GNSS provides an undisputed time reference, since satellites are synchronized to continuously corrected atomic clocks. Thus, it is used to correctly reference the INS data and to consequently synchronize them to the GNSS and LS data.

The selected INS device features a dedicated serial input for external GNSS aiding. Standard GNSS messages can be used to synchronize the unit with GPS time and to improve heading and attitude measurements. In this particular case, the rover GNSS receiver outputs NMEA messages to the INS via a serial interface. The INS in turn tags its data with the GPS time. This technique avoids any time delay that could be induced, if the PC was used as a time reference.

4.4 Initial Results

There are numerous parameters that may influence the performance of the algorithms for the data fusion of GNSS and INS. The following results display the effect of some of the most important operational parameters, such as the choice of measurement model and data sampling frequency. In all cases, the position solution acquired with the application of the EKF using RTK GNSS and INS measurements is compared to the position solution acquired with PPP. The mean and standard deviation are reported with respect to the absolute values of their differences.

Table 1 displays the results for the loosely coupled implementation using GNSS data collected at 1 Hz, using only GPS signals and 10 degrees for the mask angle. Table 2 displays the same results, for GNSS data collected at a frequency of 20 Hz. The use of higher sampling frequencies results in smaller deviations from the PPP solution, which is considered accurate within decimeter range. This is an expected result, since the position errors coming from the noisy INS data are more frequently corrected by the GNSS measurements and the applications of the EKF.

The PVT solution also allows for the inclusion of GNSS derived velocity in the measurement vector. In general, velocity measurements tend to smooth the results of the EKF and increase the accuracy of position results. Table 3 displays results for the loosely coupled implementation using GNSS derived velocity measurements at 20Hz, using only GPS satellites and 10 degrees for the mask angle. The results for the same data without the use of the velocity measurements are displayed in Table 4. The application of velocity measurements results in a better agreement with the PPP solution. Besides reducing the differences of mean and standard deviation, the maximum difference is also reduced.

Table 1. Difference between the EKF position solution and the PPP position solution, using 1Hz GNSS data.

Mean of differences (m)	North	East	Height
	1.3541	0.4940	1.7872
Standard Deviation of differences (m)			
	1.4562	0.3174	1.9411

Table 2. Difference between the EKF position solution and the PPP position solution, using 20Hz GNSS data.

Mean of differences (m)	North	East	Height
	0.1565	0.1478	1.9854
Standard Deviation of differences (m)			
	0.0415	0.0950	0.0950

Table 3. Difference between the EKF position solution and the PPP position solution, using velocity measurements.

Solution differences	North	East	Height
Mean of differences (m)	0.0386	0.0240	0.0891
Maximum of differences (m)	0.9047	0.6364	1.8001
Standard Deviation of differences (m)	0.0850	0.0455	0.1228

Table 4. Difference between the EKF position solution and the PPP position solution, without velocity measurements.

Solution differences	North	East	Height
Mean of differences (m)	2.3002	2.1938	2.4728
Maximum of differences (m)	0.8644	0.7168	0.6031
Standard Deviation of differences (m)	0.7043	0.5774	0.4976

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